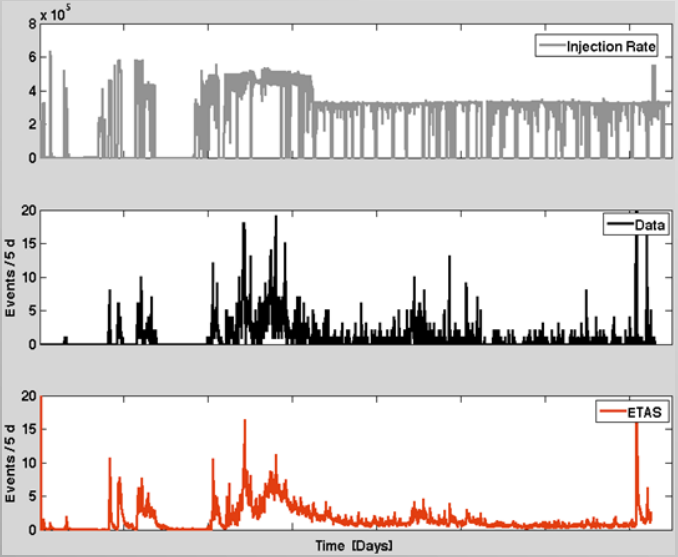


Presenter: *Corinne Bachmann and Josh White*
LBNL and LLNL

EARTH & ENVIRONMENTAL SCIENCES

NRAP Tool Webinar Series

Webinar 7

Short term seismic forecasting tool -STSF

Monday November 30, 2015

NRAP
National Risk Assessment Partnership

OVERVIEW

- Welcome and Overview of NRAP – Technical Approach and Tool Development
- Introduction to the NRAP Short Term Seismic Forecasting Tool (STSF)
- What does STSF do?
- What is the Empirical Type AfterShock (ETAS) model?
- How to run to the STSF tool
    - What input is needed
    - What output is created
- Questions and Open Discussion

National Risk Assessment Partnership (NRAP)

NRAP leverages DOE's capabilities to help quantify uncertainties and risks necessary to remove barriers to full-scale CO_2 storage deployment.

Objective: Building toolset and improving the science base to address key questions about potential impacts related to release of CO_2 or brine from the storage reservoir, and potential ground-motion impacts due to injection of CO_2

Technical Team

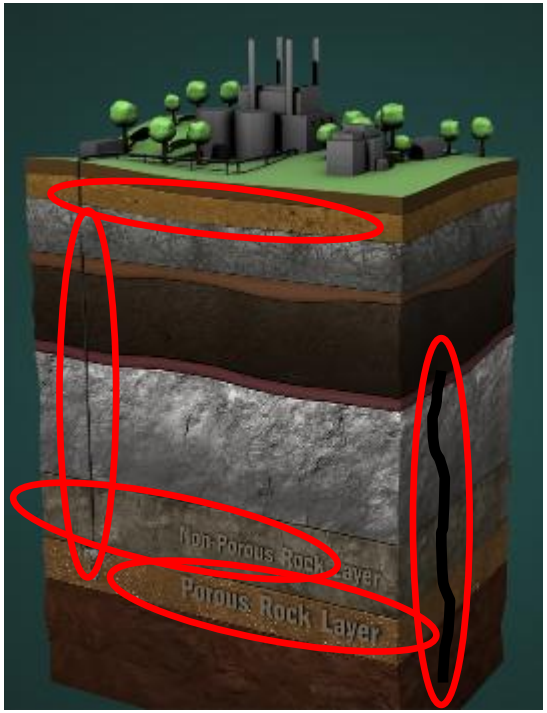
NETL

Berkeley Lab

Los Alamos National Laboratory EST.1943

Lawrence Livermore National Laboratory

Pacific Northwest National Laboratory



Stakeholder Group

American Electric Power

Blue Source

bp

EPA United States Environmental Protection Agency

ExxonMobil

ieaghg

IEc

MIT

NRDC

Schlumberger

Southern States Energy Board

Stanford University

Texas Railroad Commission

USGS

The University of Utah

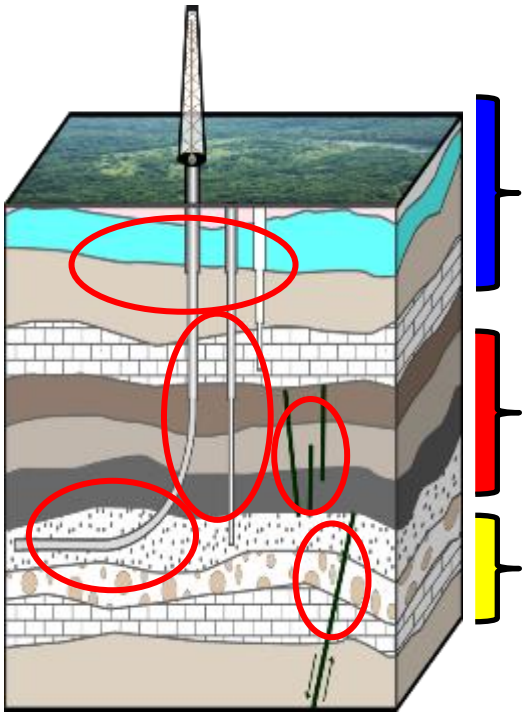
Wade, LLC

Whiting

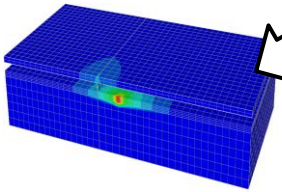
Zurich — Because change happens

NRAP's approach to quantifying performance relies on reduced-order models to probe uncertainty in the system.

A. Divide system into discrete components



B. Develop detailed component models that are validated against lab/field data



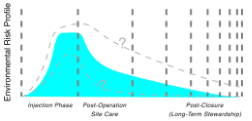
Energy Data Exchange (EDX)

Data

C. Develop reduced-order models (ROMs) that rapidly reproduce component model predictions

IAM

NRAP Integrated Assessment (System) Models



Potential Receptors or Impacted Media

Release and Transport

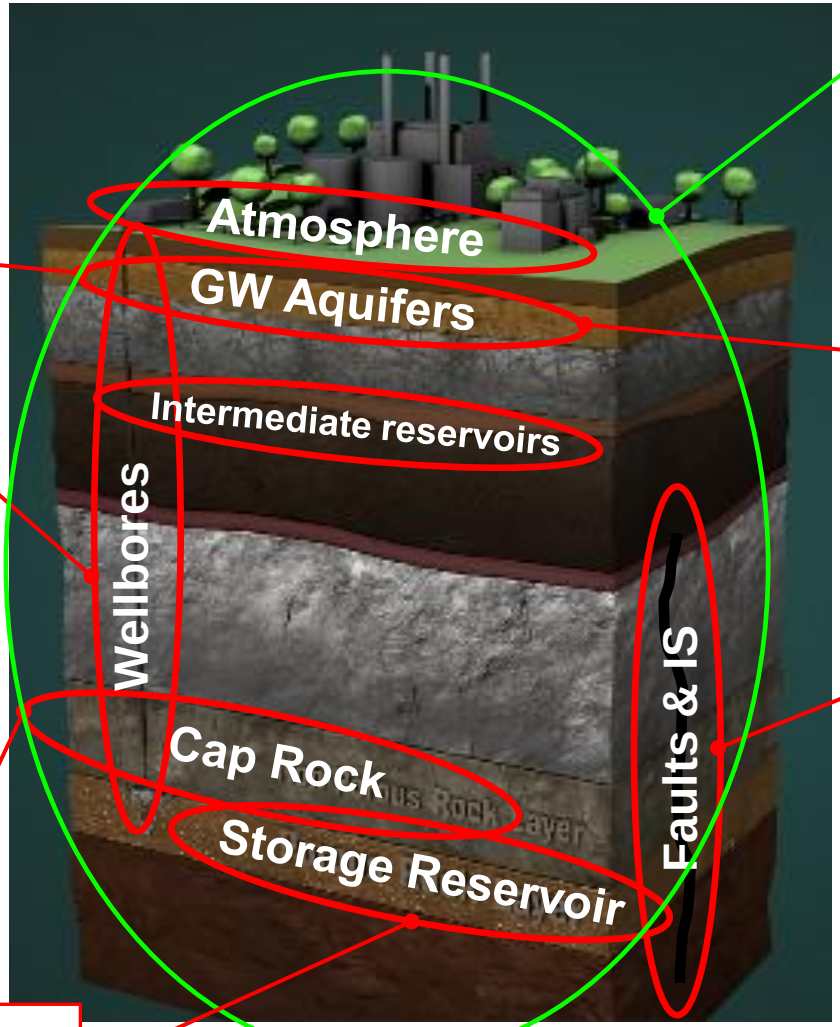
Storage Reservoir

D. Link ROMs via integrated assessment models (IAMs) to predict system performance & risk; calibrate using lab/field data from NRAP and other sources

E. Develop strategic monitoring protocols that allow verification of predicted system performance

NRAP Tools

Now available for beta testing



NRAP-IAM-CS

Design for Risk Evaluation and Monitoring

Aquifer Impact Model

Wellbore Leakage Analysis Tool

Short Term Seismic Forecasting

Natural Seal ROM

Reservoir Evaluation and Visualization

www.edx.netl.doe.gov/nrap → *TOOL BETA TESTING link*

Schedule for NRAP Tool Webinar Series

Date/ Time	Tool	Presenter(s)
October 13 Time: 1pm ET	Integrated Assessment Model–Carbon Storage (NRAP-IAM-CS) (2.5 hours)	Rajesh Pawar
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Check for updates at www.edx.netl.doe.gov/nrap

What does STSF do?

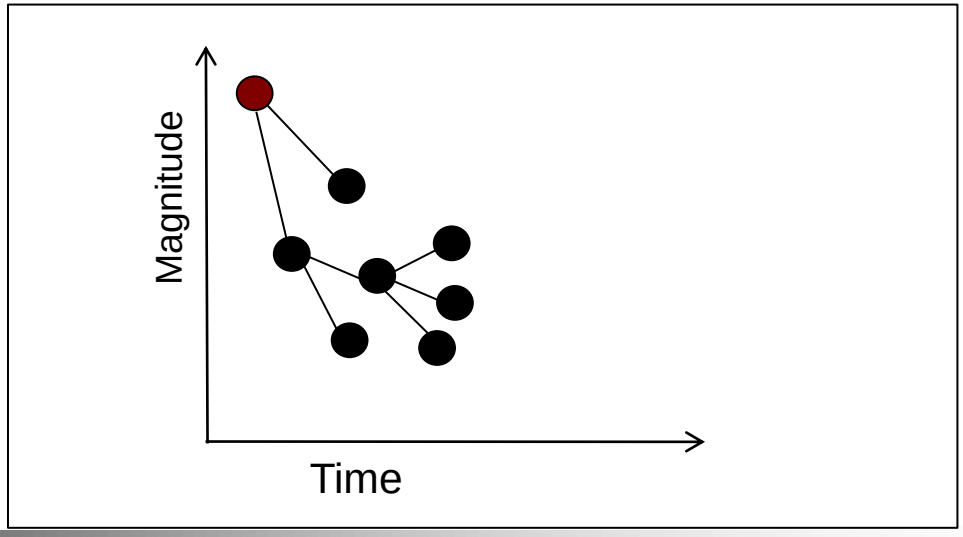
Problem statement:
We have ongoing seismicity during an injection and we want to model the behavior of the events.

Solution:
The STSF tools uses a model developed for the decay of aftershocks of large seismic events to determine the event rate in future time bins. It also fits the injection parameters of the ongoing project

- Uses the ETAS model
- Can use different injection parameters as input
- Predicts event rates above a pre-determined magnitude threshold
- Can be used in real-time in an ongoing project

Epidemic Type Aftershock Sequence Model (ETAS)

- **Originally developed by Ogata in 1988 to determine the occurrence of aftershock after a main shock / large event.**
  - Each earthquake has the ability to trigger aftershocks
  - ETAS is a cascading model



Epidemic Type Aftershock Sequence Model (ETAS)

- **Originally developed by Ogata in 1988 to determine the occurrence of aftershock after a main shock / large event.**

$$\lambda_i(t) = \frac{K}{(c + t - t_i)^p} 10^{\alpha(M_i - M_{\min})}$$

$$\lambda(t) = \lambda_0 + \sum_{[i:t<t_i]} \lambda_i(t)$$

Background Term

Triggered Term

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Epidemic Type Aftershock Sequence Model (ETAS)

- **To adapt for injection induced seismicity, a term is added into the background:**

$$\lambda(t) = \lambda_0 + \sum_{[i:t<t_i]} \lambda_i(t)$$

- ***Fr(t)* is originally the injection rate, but this can be adapted, *cf* is a fitted constant**

$$\lambda_0(t) = \mu + c_f \times F_r(t)$$

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ETAS Code

- **There are several adaptions of the ETAS frame set**
  - We use a code written by Prof. S. Hainzl at GFZ Potsdam
- **All codes are written in C++ and originally called by a Perl script**
- **Matric Research has turned the Perl Script into a GUI**

How to install the STSF Tool

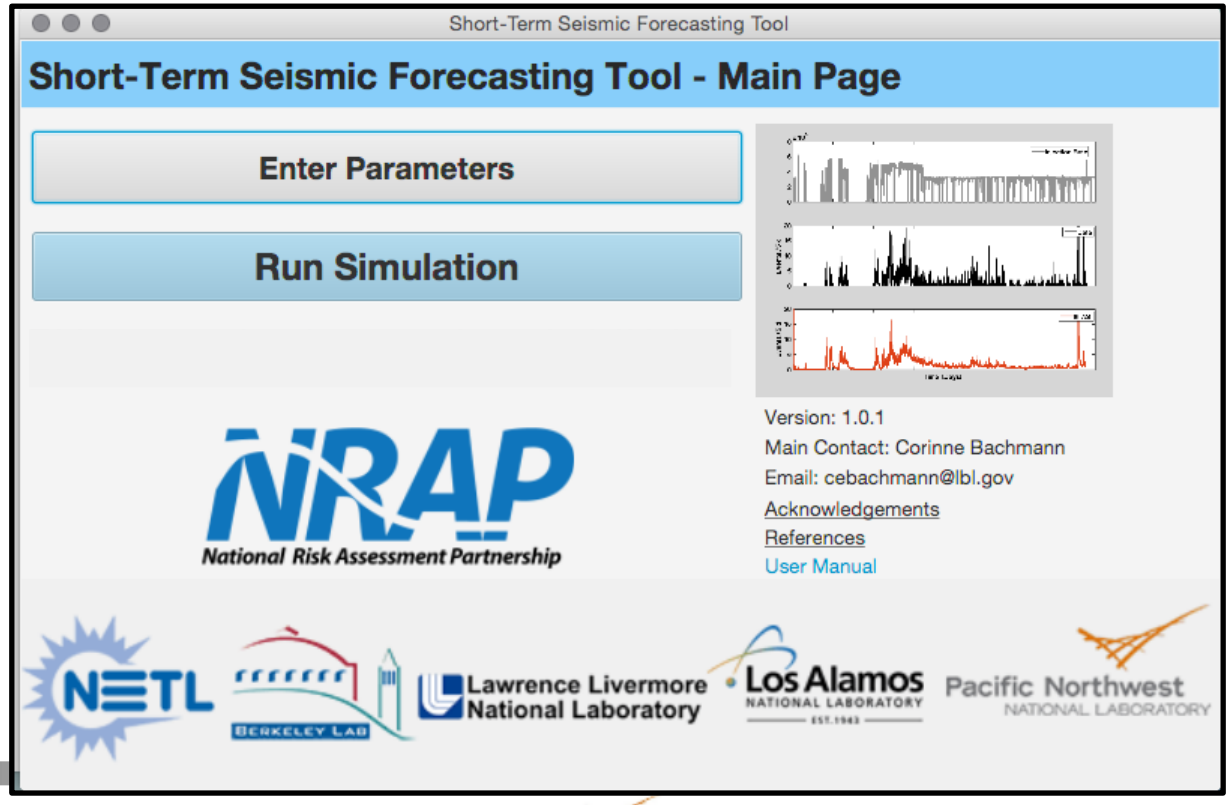
- **The tool package is a zip file on EDX**
    - Unpacking the zip file creates a folder with all files needed
- **Currently only tested on Mac OSX and Linux**
- **Requires Java Runtime Environment (JRE) version 8 update 40 or newer**
  - Current version is 51, might need restart after update
- **Requires gcc**

How to run the STSF Tool

- **To run the GUI**

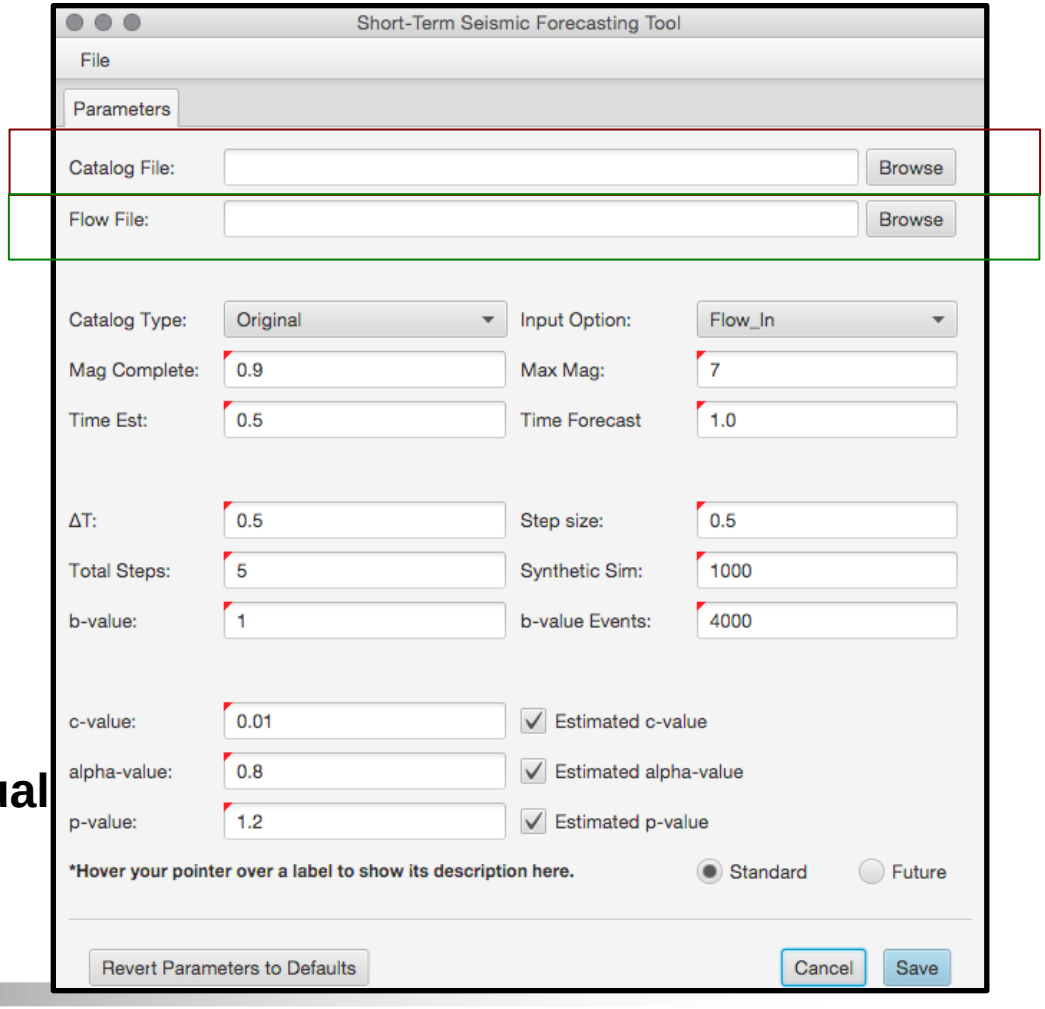
  sh bin/application

- has to be run in a shell script from the main tool folder



GUI- Input

- **The GUI needs two files**
  - Catalog Data
  - Injection Data



The format of both files is described in the User Manual

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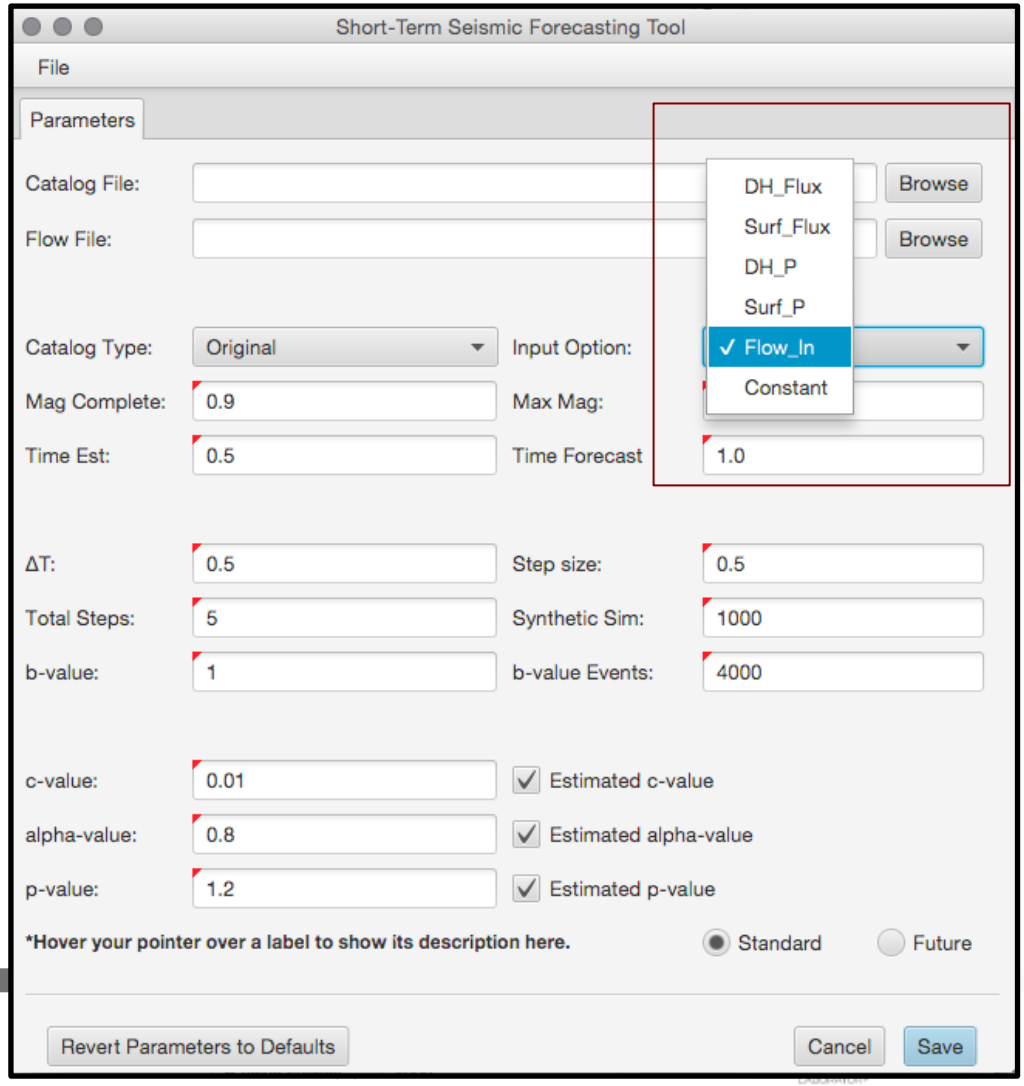
GUI- Options

- **Different input parameters can be used for *Fr***

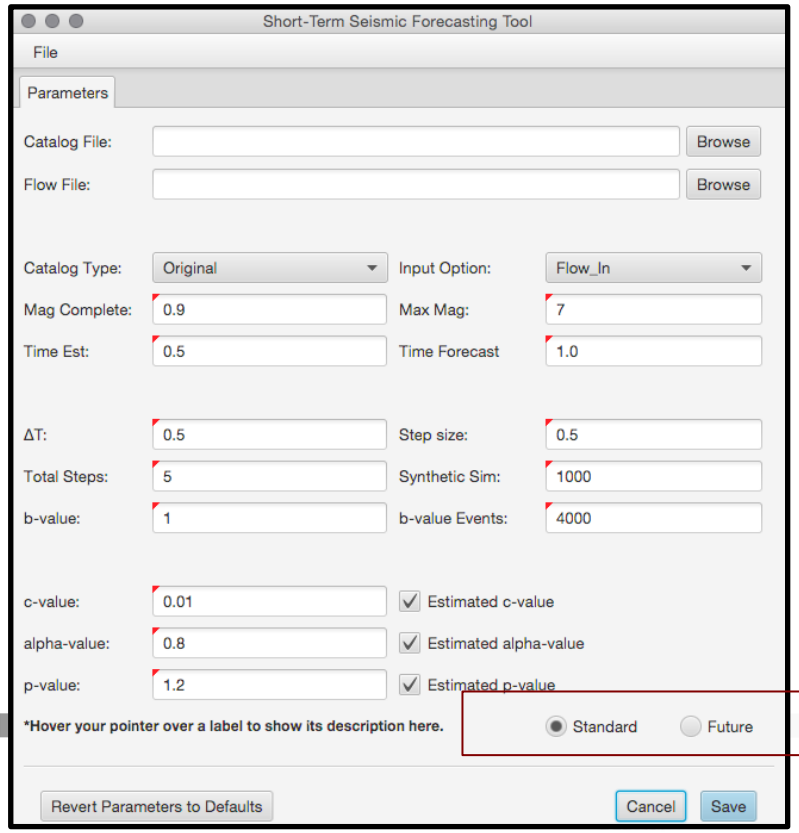


DH = Downhole
Surf = Surface

(Examples from a previous experiment, can be adapted)

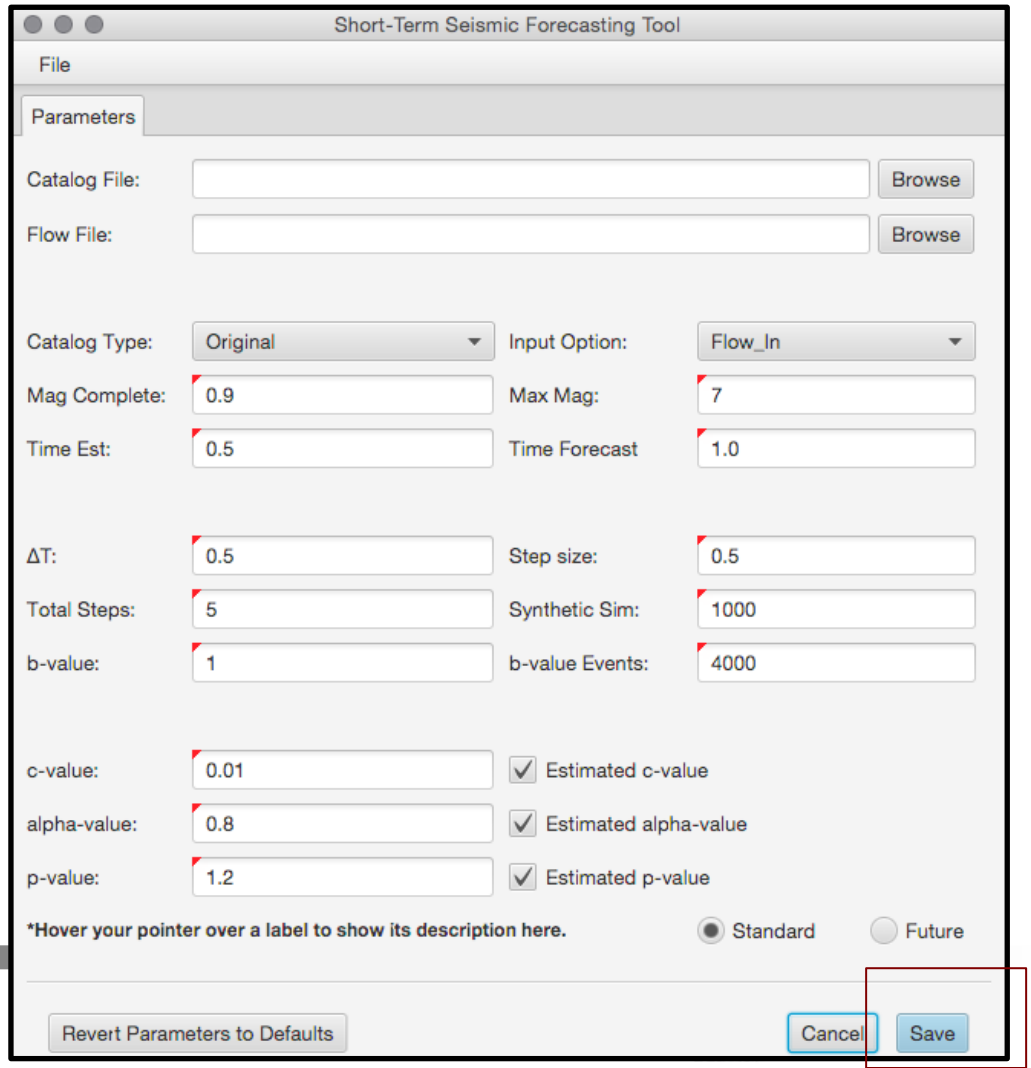
GUI- Options

- **Information about flow parameter in forecast time-bin can be included with the '*future*' option**
- ***Standard* only uses past information**



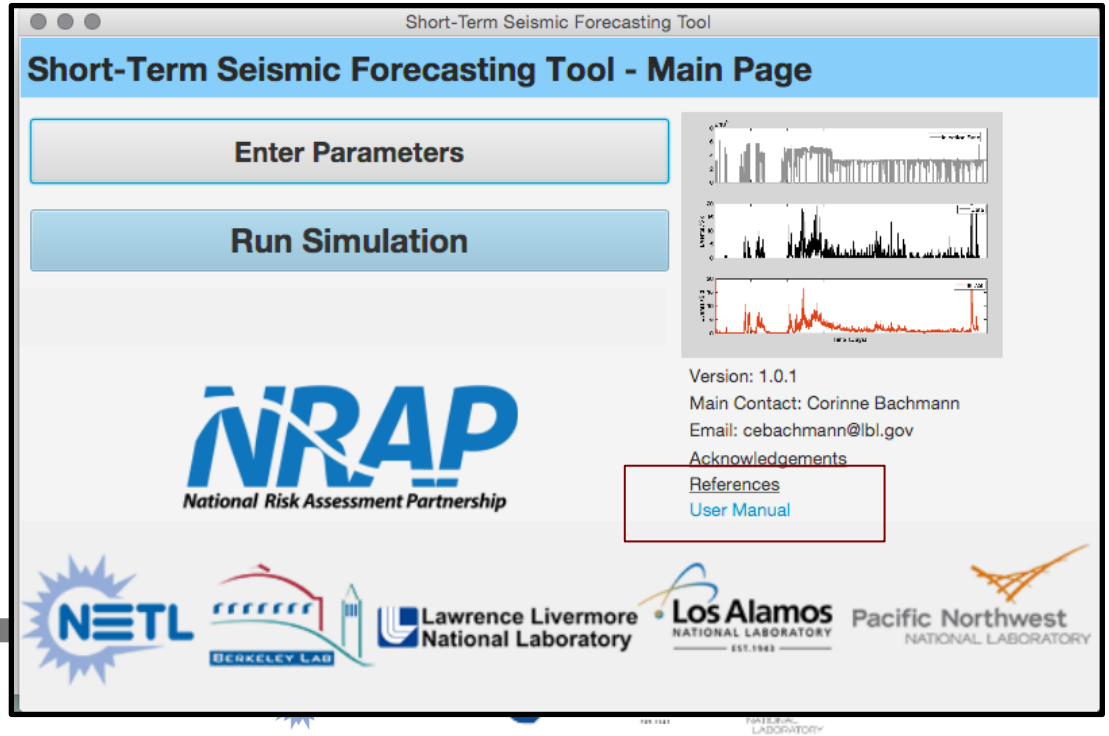
GUI- Options

- **Different input parameters can be varied/fixed**



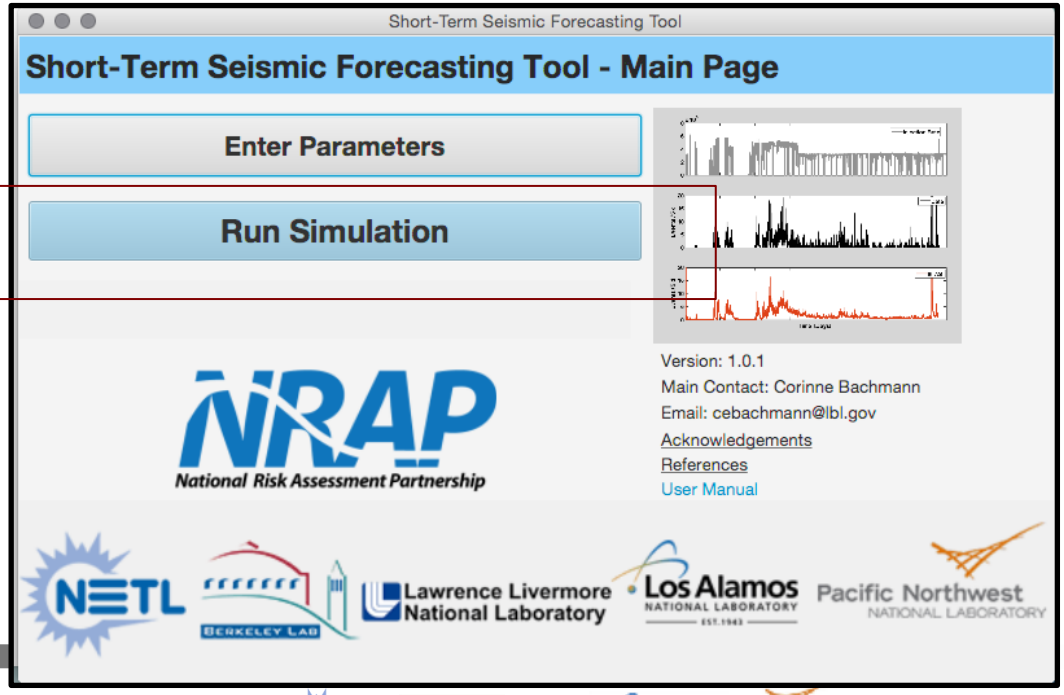
GUI- Options

- Saving parameters returns the GUI to the start frame
- More information about parameters can be found in the User Manual



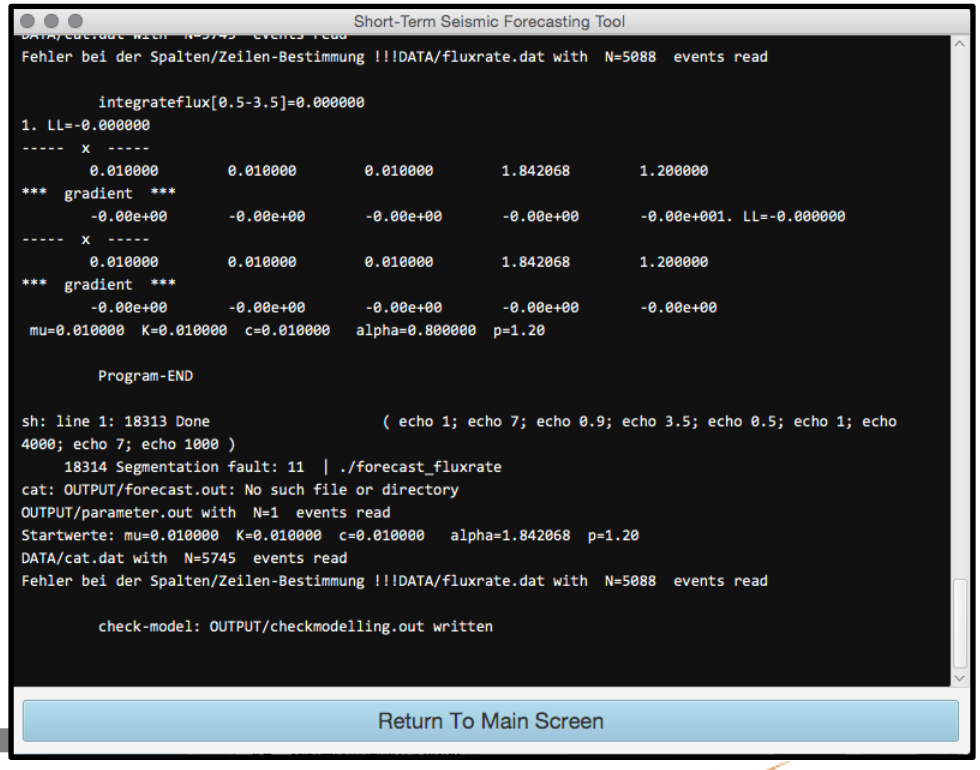
GUI- Running a simulation

- **A simulation is run with the 'Run Simulation' button**
- **Before the first run, parameters have to be set and input files have to be chosen**



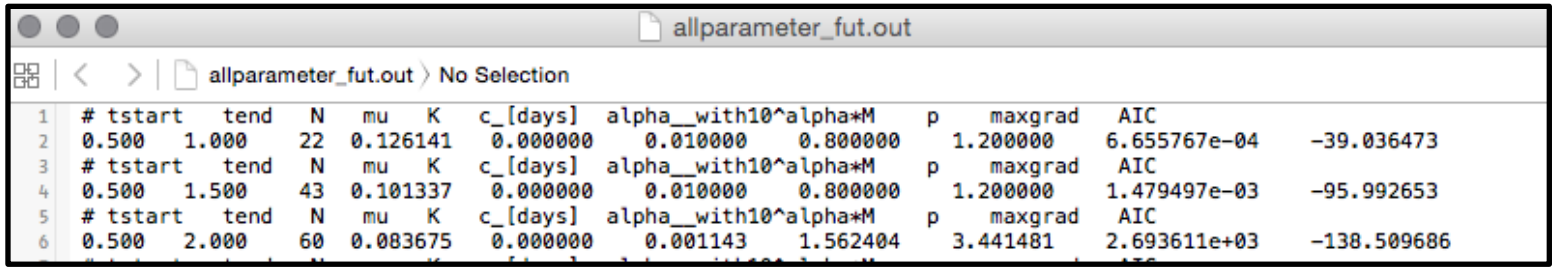
GUI- Running a simulation

- A simulation run opens a shell script output
- The run is finished when the ‘Return to Main Screen’ button is highlighted



Output files

- **Output files are written in the tool folder**
  - bin/OUTPUT
  - **One file with calculated parameters**




```
1  # tstart   tend   N   mu   K   c_[days]  alpha__with10^alpha*M    p    maxgrad   AIC
2  0.500   1.000    22  0.126141   0.000000    0.010000    0.800000    1.200000    6.655767e-04    -39.036473
3  # tstart   tend   N   mu   K   c_[days]  alpha__with10^alpha*M    p    maxgrad   AIC
4  0.500   1.500    43  0.101337   0.000000    0.010000    0.800000    1.200000    1.479497e-03    -95.992653
5  # tstart   tend   N   mu   K   c_[days]  alpha__with10^alpha*M    p    maxgrad   AIC
6  0.500   2.000    60  0.083675   0.000000    0.001143    1.562404    3.441481    2.693611e+03    -138.509686
```

  - **One file with calculated rates**

```
1  1.000000    1.500000    29.460000
2  1.500000    2.000000    23.425000
3  2.000000    2.500000    31.699000
```

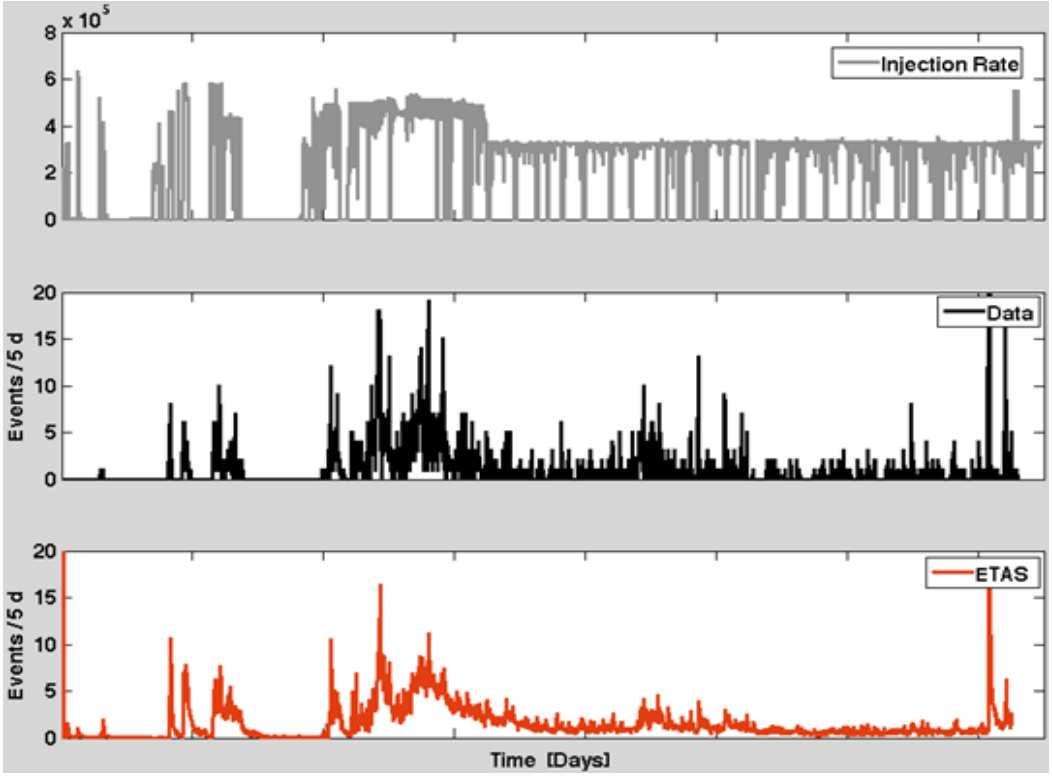
    - **From day 1 to 1.5 29.46 events above magnitude of completeness were forecast**

Output files

- **Output files are written in the tool folder**
  - bin/OUTPUT
  - The files have a standard name and will be overwritten by a new run
    - allforecast_fut.out and allparameter_fut.out
  - To save the output of one run, files have to be renamed manually
    - Possibility of determining output name files could be added in a newer version

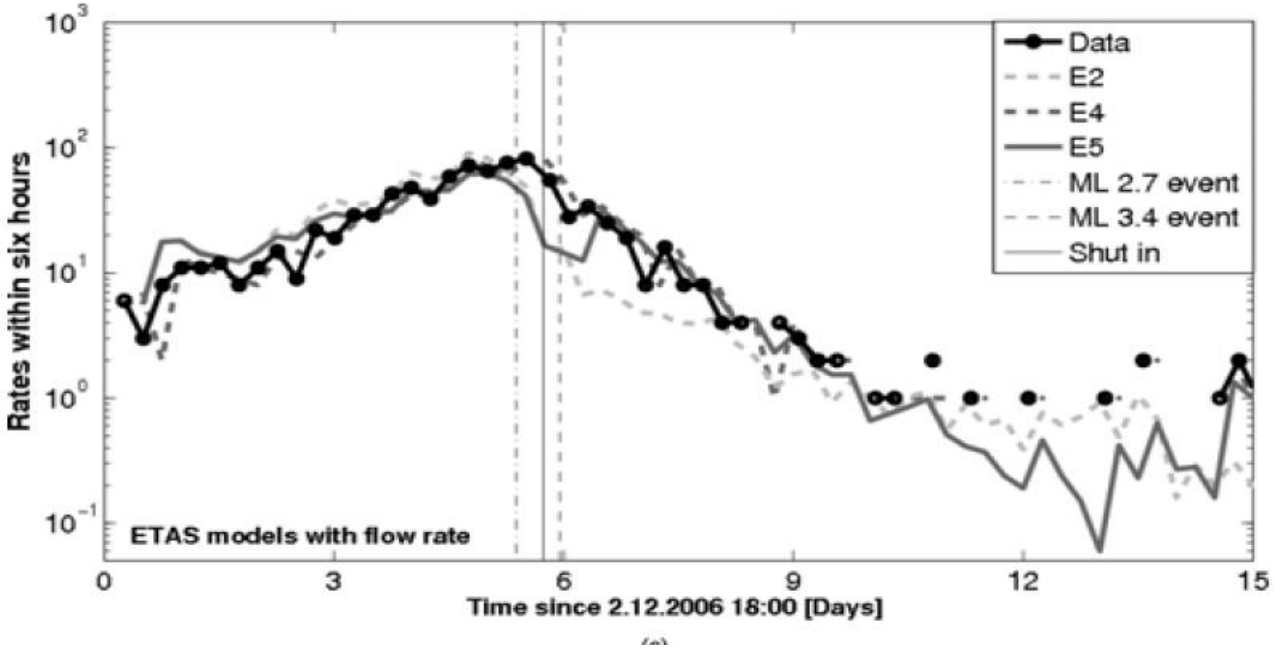
Output Examples

- **Output example with event forecast in 5 day bins over a 20 year injection**



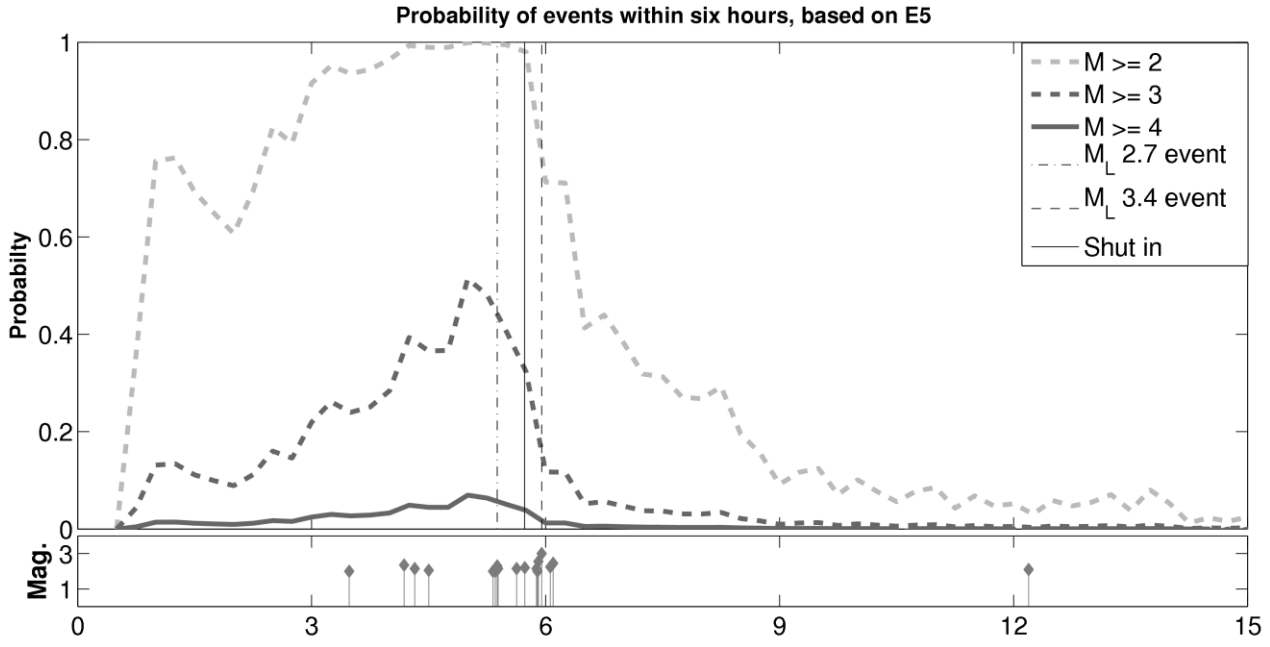
Output Examples

- **Output example with event forecast in 0.25 day bins for a 6 day injection**
  - **E2,E4 and E5 are different realizations of the model**



Output Examples

- **Events above a certain magnitude with time**



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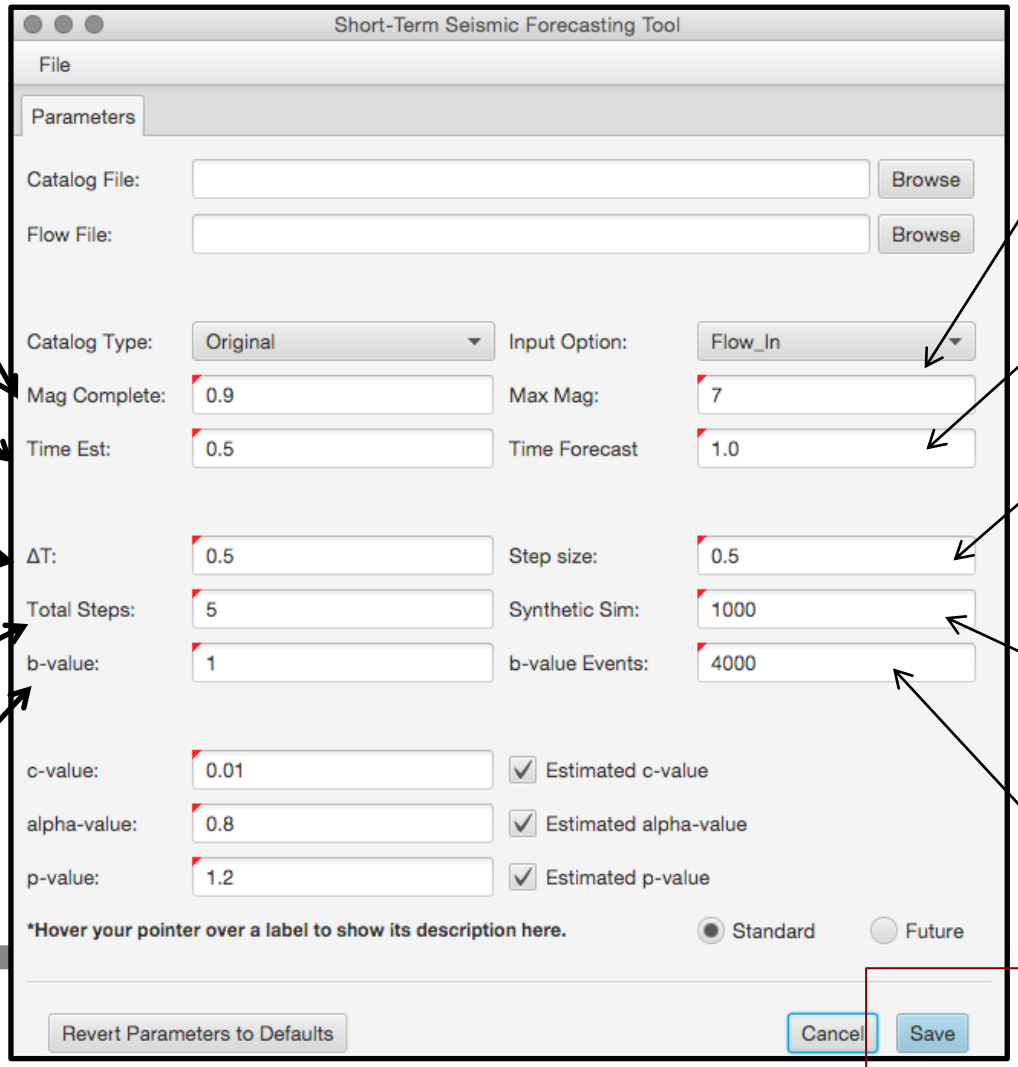
Questions?

Seismic Short Term Forecasting (STSF) tool

Questions/comments not addressed during the scheduled meeting time can be addressed to cebachmann@lbl.gov

GUI- Options

- **Different input parameters can be varied/fixed**



Magnitude of completeness of input catalog

Time when the first parameters will be estimated

Size of forecast window in days

Total number of time steps to forecast

b-value of GR law

Maximum Magnitude assumed for forward simulation

Size of forecast window in days

Step size between time windows

Number of synthetic forward

Number of events needed to determine b-value